Permittivity and loss characteristics of SU8-quartz composite photoresist at THz frequencies

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Abstract

An SU8-quartz composite photoresist has been fabricated and characterized from 1.2 to 1.4 THz; the material contains quartz particles from 0 to 50 wt%. The composite can reduce the inherent losses of SU8 photoresist at terahertz frequencies. Calculated and measured data is presented and compared to SU8 without quartz inclusions. The results show a reduction in losses and an increase in permittivity in the composite material as the density of quartz particles increases. This initial experiment proves the possibility of modifying the electrical parameters of SU8; increasing the quartz density of the composite will modify these parameters further at THz frequencies.

Introduction

SU8 has been recently used to produce terahertz circuits, these components consist of micromachined waveguides [1]. These circuits are made with low cost and a simple fabrication technique, where the SU8 is metallized, thus there is no electromagnetic field in the SU8 photoresist and the losses in the SU8 are therefore immaterial.

Circuit design can become more flexible if parts of the SU8 are not metallized [2], this can open up a new generation of millimeter-wave/terahertz circuits. It is well known that SU8 attenuates the signal due to its inherent high loss if used as a dielectric [3, 4]. In this study we demonstrate the possibility of lowering the loss of the SU8 by adding quartz nano-particles with a diameter of 1 μm for high packing density. For the case reported here the SU8 samples were prepared with 10 wt%, 30 wt% and 50 wt% quartz density.

Water content in the atmosphere leads to propagation attenuation of THz signals. Two potential windows in an Albuquerque atmosphere for THz propagation include the bands from 1.2 to 1.4 THz and 1.4 to 1.6

THz as reported in [5]. In this letter, terahertz spectroscopy measurements from 1.2 to 1.4 THz are done to find the composite´s permittivity and loss tangent and compared to a plain SU8 sample. The results show a reduction of loss tangent and an increase in permittivity as the quartz density increases from 1.2 to 1.4 THz.

Fabrication

SU8-50 photoresist was used in this experiment. In order to have 50 wt% of quartz inside the finished material, we typically add 1 gram of quartz powder into 1.3 grams of SU8-50 photoresist. That is because there is around 30% of solvent (Gamma Butyrolactone) inside the photoresist, which will evaporate during the subsequent processing. A small amount of extra Gamma Butyrolactone solvent was added during the mixing in order to improve the uniform distribution of the quartz powder. We added the calculated amount of quartz powder for the composite photoresist with a different quartz wt%.

The photolithographic processing steps of SU8 containing quartz are basically the same as plain SU8 on a silicon substrate [1], which consists of resist spinning, pre-bake, UV exposure, post-bake and development. The UV exposure time needs to be increased by about 15% with resist containing quartz for the thickness of 190 μm, used for the samples. The silicon substrate is removed by KOH solution leaving only the composite photoresist for THz measurements. Fig. 1 shows the optical photograph of the fabricated composite photoresist. The optical brightness gets darker as the quartz density increases. As expected, the diffused reflection caused by quartz nanoparticles leads to a dark and opaque material.

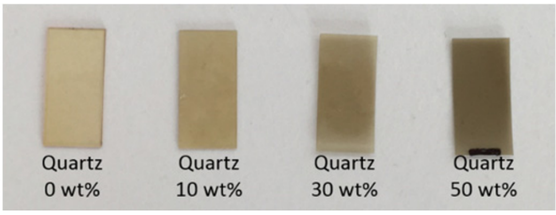


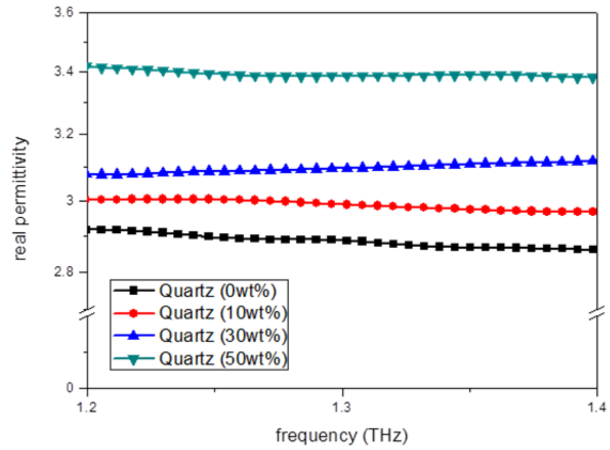
Fig. 1 *Optical photograph of the fabricated composite photoresist.*

Measurement and result

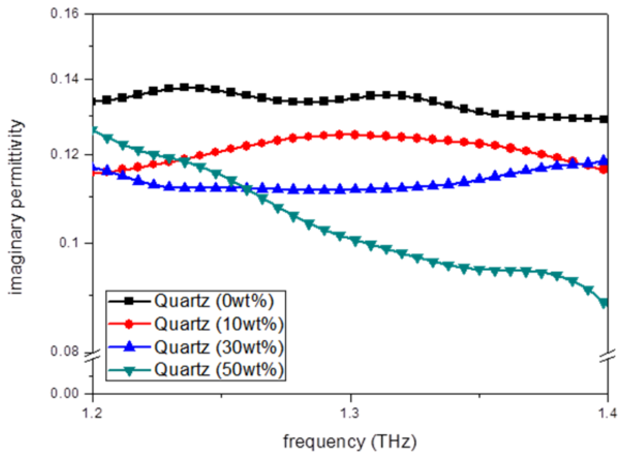
A TeraView Ltd. TPS Spectra 3000 spectrometer has been used to measure the samples. It uses a femtosecond laser operating at 800 nm with bandwidth limited pulses of less than 100 fs to excite a slab of gallium arsenide (GaAs) semiconductor. The near infrared pulse is above the band gap of GaAs and this generates electron-hole pairs. Applying an electric field to the device accelerates the photocarriers to generate a burst of coherent terahertz photons (or waves). These photons can be detected by optically gating another GaAs semiconductor switched by the same laser pulse. Varying the delay between the terahertz generating pulse and the optical gate allows a terahertz waveform to be reconstructed at a rate greater than 30 waveforms per second.

In a THz time domain spectroscopy experiment the measurement is performed recording two traces, one where the THz pulse propagates through the sample and other where the THz pulse propagates through the air. From this data it is possible to extract information about the complex dielectric properties of the sample [6].

The permittivity and loss tangent of SU8 without quartz and SU8-quartz composite are measured using the above experimental set up. All measurements shown in this letter (Fig. 2 and Fig. 3) are raw data of the permittivity and loss tangent calculated from 1.2 to 1.4 THz. Fig. 2a and Fig. 2b show the measured real and imaginary permittivity of the composite photoresist, respectively. Adding quartz nanoparticles leads to higher real permittivity and lower imaginary permittivity because the quartz substrate and SU8 have a real permittivity value of around 4.47 and 2.92 at 1 THz [7, 8], respectively. The effective real permittivity of the SU8-quartz composite photoresist can be calculated by taking the literature value [7, 8] and using Maxwell-Garnett expression [9] which allows the analysis of a composite material in terms of permittivity and material densities.



a



b

Fig. 2 *Measured permittivity of the composite photoresist as a function of frequency according to quartz wt%*

a real part of permittivity

b imaginary part of permittivity

Fig. 3 shows the calculated loss tangent using the measured real and imaginary permittivity of the composite photoresist. The loss tangent decreases according to the increase of quartz density in the range from 1.2 to 1.4 THz. Especially the loss tangent of the composite photoresist with 50 wt%-quartz decreases as frequency increases between 1.2 to 1.4 THz. The low loss characteristic will be very useful for THz applications since the loss of plain SU8 increases as frequency increases at THz frequencies [8]

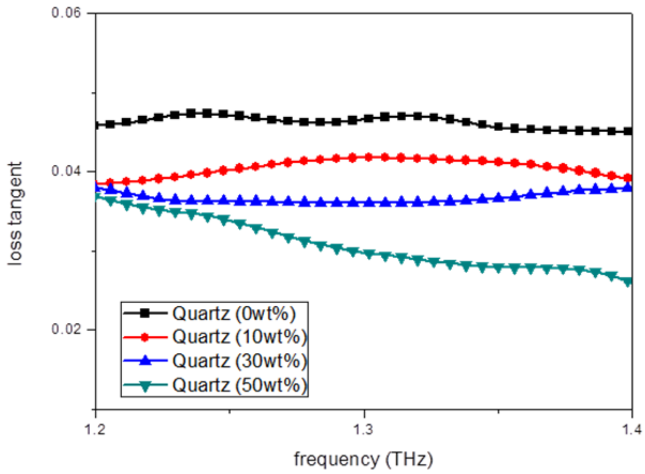


Fig. 3 *Measured loss of the fabricated composite photoresist.*

Conclusion

In this letter an SU8-quartz composite photoresist to lower the losses inherent with SU8 photoresist is described. As an initial experiment, a composite photoresist based on SU8 with 0 to 50% quartz density has been fabricated and measured. The results show that the losses can be diminished at THz frequencies. Further work should be focused on the production of a higher quartz density composite photoresist to further lower the losses of plain SU8.

Acknowledgments

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References

1. Yingtao Tian, Xiaobang Shang, Michael J. Lancaster.: 'Fabrication of multilayered SU8 structure for terahertz waveguide with ultralow transmission loss'. *J. Micro/Nanolith. MEMS MOEMS* 2014, **13**, (1)

2. J.Thorpe, Steenson D. and Miles R.E.: ‘High frequency transmission line using micromachined polymer dielectric’. *Electronics Letters*, 1998, **34**, pp. 1237-1238

3. Arscott S., Garet F., Mounaix P., Duvillaret L., Coutaz J.-L. and Lippens D.: ‘Terahertz time-domain spectroscopy of films fabricated from SU-8’. *Electronics Letters*, 1999, **35**, (3), pp. 243-244

4. Lucyszyn S.: ‘Terahertz time-domain spectroscopy of films fabricated from SU-8’. *Electronics Letters*, 2001, **37,** (20), pp.1267-1267

5. Robert J Foltynowicz, Michael C. Wanke, and Michael A. Mangan,: ‘Atmospheric propagation of THz Radiation’. (Sandia Report, 2005)

6. Grant. R. Fowles,: ‘Introduction to Modern Optics, 2nd ed’. (Dover Publications, 1975)

7. http://www.tydexoptics.com/products/thz_optics/thz_materials/

8. Nima Ghalichechian, and Kubilay Sertel,: ‘Permittivity and Loss Characterization of SU-8 Films for mmW and Terahertz Applications’. *IEEE Antennas Wireless Propag. Lett.,* 2008, **7**, pp. 723–726

9. European Commission, Nanostructured Metamaterials – Exchange between experts in electromagnetics and material science, Luxembourg: Publications Office of the European Union 2010, pp. 31-33, ISBN 978-92-79-07563-6